



Identification of critical habitat in a data-poor area for an Endangered aquatic apex predator

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ABSTRACT

Conservation often focuses on “critical habitat” including areas important for the reproduction of threatened taxa. As for many aquatic species a priority of shark conservation is the protection of nurseries, yet few countries can support the costly fieldwork required to identify these according to strict criteria. Alternative approaches are therefore required where resource, capacity and security constraints exist. This study collates low-resolution data from alternative, remotely collected and inexpensive existing sources (fish market surveys, literature, museums, anecdotal accounts), to evaluate a possible nursery for the regionally Endangered bull shark (*Carcharhinus leucas*) in the Tigris-Euphrates system and adjacent northwestern Persian/Arabian Gulf (Iraq, Iran, Kuwait), a data-poor area long characterised by conflict and inaccessibility. Evidence is presented that aligns with two of the three nursery definition criteria (abundance and repeated use), along with other data supporting known *C. leucas* reproductive behaviour. While the necessarily low resolution data cannot answer the full suite of strict nursery criteria nor identify precise nursery locations, they nevertheless collectively provide compelling evidence for a broad area of importance to young and juvenile *C. leucas*. This area is both highly threatened (e.g. by damming, climate change, fisheries) and of potential major significance, given the apparent absence of similar estuary habitat for thousands of kilometres of arid northwestern Indian Ocean coast. The inexpensive desk-based approach to identifying critical habitat provides another toolkit option for conservationists and could best be applied to distinctive threatened aquatic taxa, especially in the developing world where conservation is often resource-limited.

1. Introduction

Biodiversity conservation often prioritises areas of ‘critical habitat’, a term whose use ranges from the informal for areas of elevated importance (e.g. Kelaher et al., 2015) to that defined by strict criteria, such as used by the US Endangered Species Act (ESA) and the International Finance Corporation (IFC). Often, critical habitat recognises the value of both highly threatened species and areas essential for their reproduction. For example, IFC critical habitat criterion 1 includes consideration of habitat ‘required to sustain’ IUCN *Red List* Critically Endangered or Endangered species, as does the US ESA for sites essential for breeding, reproduction and rearing of offspring (IFC, 2012; US Fish and Wildlife Service, 2017). In practice, funding and logistical concerns often constrain the identification of such areas, especially in data-poor developing or least developed countries. In these situations obtaining even the most basic information often necessitates low-resolution approaches to identify conservation priorities, such as for cetaceans in Tanzania (Braulik et al., 2017).

Sharks and their relatives have undergone well-documented

declines and face a higher risk of extinction than most other vertebrates, with species that are both large-bodied and reliant on river systems identified as being particularly at risk (Dulvy et al., 2014). The aim of the 1998 International Plan of Action for Conservation and Management of Sharks is to ensure the global conservation and management of sharks and their relatives, and one of its goals is the identification of critical habitats such as nursery and pupping areas (FAO, 2017a). However, an explicit definition of a shark nursery was lacking until that proposed by Heupel et al. (2007). These authors highlighted that the occurrence of young sharks alone is not sufficient evidence, as it would likely result in most coastal areas being identified as nurseries. Heupel et al. (2007) proposed a definition of a shark nursery based on three criteria being met for “young” (neonate and < 1 year old) sharks. These were that young sharks 1) were more commonly encountered in the area than in other areas, 2) have a tendency to remain or return in the area for extended periods, and 3) use the area or habitat repeatedly across years (Heupel et al., 2007). While these criteria are currently the best available, authors testing them against a large dataset have noted that areas not qualifying as nurseries may still be of significant

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importance to juvenile sharks (Froeschke et al., 2010).

The shark nursery concept has been tested in countries with well-developed shark research programs using costly, extensive, and/or long-term field surveys to identify nursery areas: the USA (Froeschke et al., 2010; Curtis et al., 2011), Australia (Thorburn and Rowland, 2008) and South Africa (Hussey et al., 2009). Multi-faceted studies that involve less exhaustive field surveys have also advanced our knowledge of euryhaline coastal shark reproductive behaviour (Werry et al., 2011), but still rely on significant fieldwork and resources. These surveys, in a handful of countries, are not reflective of reality along coastlines of developing or least developed countries where elasmobranch research is absent or limited due to resource, capacity and other constraints. Alternative and complementary approaches are clearly needed to inform conservation and management in these locations.

A range of relatively inexpensive and land- or desk-based data collection techniques are available to shark researchers to directly inform conservation, including fish market surveys (e.g. White, 2007) and collating catch data from recreational anglers (Ajemian et al., 2016), the latter of which has been used to identify potential nursery grounds (Dicken et al., 2006). The growing field of marine historical ecology (MHE) draws on a range of alternative data sources such as archaeology, anecdotes, museum specimens and old photographs to inform conservation (Lotze and McClenachan, 2014), and MHE studies on marine megafauna in the Arabian region have documented rare species, identified potential areas of importance, and reconstructed historical baselines of sawfishes and dugongs (Moore, 2010, 2011, 2015; Al-Abdulrazzak and Pauly, 2017).

The bull shark (*Carcharhinus leucas*) is found in shallow warm coastal waters worldwide, although molecular data suggest it represents a cryptic species complex (Naylor et al., 2012; Ebert et al., 2013). *Carcharhinus leucas* is euryhaline and apparently reliant on freshwater and estuary systems for nurseries which are thought to provide a low-mortality environment for young (Heupel and Simpfendorfer, 2011). The occurrence of this large (maximum recorded total length (TL) 400 cm, McCord and Lamberth, 2009) shark in river systems has attracted research for decades across the globe, from the Amazon to Fiji (Thorson, 1972; Cardenosa et al., 2016). In the Middle East, it has been known since antiquity that sharks occur in the Tigris-Euphrates system (Zorzi, 1995; Moore and McDavitt, 2009), from where there have been numerous recorded incidents of them biting humans (Wilson, 1941; Hunt, 1951; Thesiger, 1964; Coad and Papahn, 1988; Coad and Al-Hassan, 1989). There has however apparently been little or no research interest in the ecology of *C. leucas* there. A notable exception was in the late nineteenth century, when Dr. Albert Günther of the British Museum examined a young specimen from the Tigris at Baghdad and noted “It would be a point of great interest to ascertain whether this fish spawns in the river...or whether it descends to the sea for that purpose” (Günther, 1874, p. 36). *Carcharhinus leucas* has been assessed as Endangered in the Arabian region (Simpfendorfer et al., 2017).

The aim of the present study is to investigate the possible presence of a *C. leucas* nursery in the Tigris-Euphrates system and adjacent waters of the Persian (Arabian) Gulf (‘the Gulf’ hereafter) using available data, including testing it against the criteria of Heupel et al. (2007).

2. Methods and materials

2.1. Study area

The study area is centred around Kuwait and Iraq in the north-western Gulf, but also considers the wider central and southern parts of the Gulf around Bahrain and Qatar (Fig. 1). Both the Tigris and the Euphrates rivers rise in Turkey and flow through Syria and then Iraq, where they support the Mesopotamian Marshes in southern Iraq (FAO, 2017b). They then combine to form the Shatt Al-Arab River, which is then joined by the Karun River, a significant tributary rising in Iran. The

Shatt Al-Arab forms a boundary between Iraq and Iran, and discharges to the northwestern Gulf < 20 km from Kuwait's maritime border (Fig. 2). Although there are other drainages along the Iranian coast (Mand, Helleh, Hendijan) the Shatt Al-Arab is by far the main source of freshwater to the northern Gulf, where it is of major significance to marine ecological conditions and the only extensive estuarine system (Al-Yamani, 2008). The delta system in the northwestern Gulf also includes the Shadegan wetland in Iran with freshwater, tidal and marine habitats. The entire Tigris-Euphrates system has been heavily modified through extensive drainage, canal construction, damming, and irrigation projects (FAO, 2017b), such as the Shatt Al-Basrah Canal connecting the Khor Al-Zubair, an estuarine northwestern extension of the Gulf, with the marshes area. The area has been the focus of persistent armed conflict in recent decades, most notably the Iran-Iraq War (1980–1988), The Gulf War (1990–1991) and the Iraq War (2003–2011). This has restricted access to the area for ecological research and continues to do so for reasons such as military sensitivities, border disputes, and unexploded ordnance. Fisheries pressures are widely acknowledged to be intensive throughout the Gulf, and with an average depth of only 35 m makes most elasmobranchs highly available to fisheries; widespread declines in the abundance of elasmobranchs including carcharhinid sharks have been reported (Valinassab et al., 2006; Jabado et al., 2017).

2.2. Identification

Size of *C. leucas* is expressed as stretched total length (STL, caudal fin depressed), or total length (TL, caudal fin in natural position). In cases where the distinction between these was not made in the original data source, STL has been assumed, acknowledging that there is a relatively small difference between the two. All individuals were identified by the author where possible either directly or from good quality lateral photographs. While several species of *Carcharhinus* occur in the Gulf (Almojil et al., 2015), only one species, the pigeye shark *C. amboinensis*, shares with *C. leucas* key characteristics of a short blunt snout, a lack of distinct fin markings, and broadly triangular serrated upper teeth. As per Garrick (1982), the ratio of the measured height of the first to the second dorsal fins was calculated to separate *C. leucas* (< 3.1) from *C. amboinensis* (> 3.1). Records of unidentified sharks in freshwater or lower salinity environments were assumed to be *C. leucas*; *C. amboinensis* is reportedly restricted to inshore marine habitats (Ebert et al., 2013) and juveniles appear to display a low tolerance of low salinity environments (Knip et al., 2011). The enigmatic river shark genus *Glyphis* that has sometimes been confused with *C. leucas* is not known west of Pakistan (Ebert et al., 2013).

2.3. Data collection

Comparative surveys of elasmobranchs at artisanal fisher landing sites and fish markets are detailed elsewhere (Moore et al., 2012; Moore and Peirce, 2013). These identified and measured all elasmobranch individuals in the month of April and took place in Kuwait in 2008 and 2011 representing landings from fisheries operating in the north-western Gulf, while surveys in Qatar in 2009 and Bahrain in 2012 sampled the central and southern Gulf (Moore et al., 2012; Moore and Peirce, 2013). Sharks at more easterly markets in the United Arab Emirates (UAE) (Moore et al., 2012; Jabado et al., 2015, 2016) were not considered in this study as they may include individuals caught outside of the Gulf (Jabado et al., 2015, 2016). Vessels landing small sharks in Kuwait, Qatar and Bahrain are primarily small (c. 7–10 m) open speedboats operating gillnets in local coastal waters catching sharks as bycatch. Fisheries in all locations were considered as equally likely to catch and land young *C. leucas* if present, given that all elasmobranch landings regionally are dominated by smaller carcharhinids (Moore et al., 2012; Moore and Peirce, 2013; Jabado et al., 2015). Species discovery curves of the Kuwait, Bahrain and Qatar surveys also

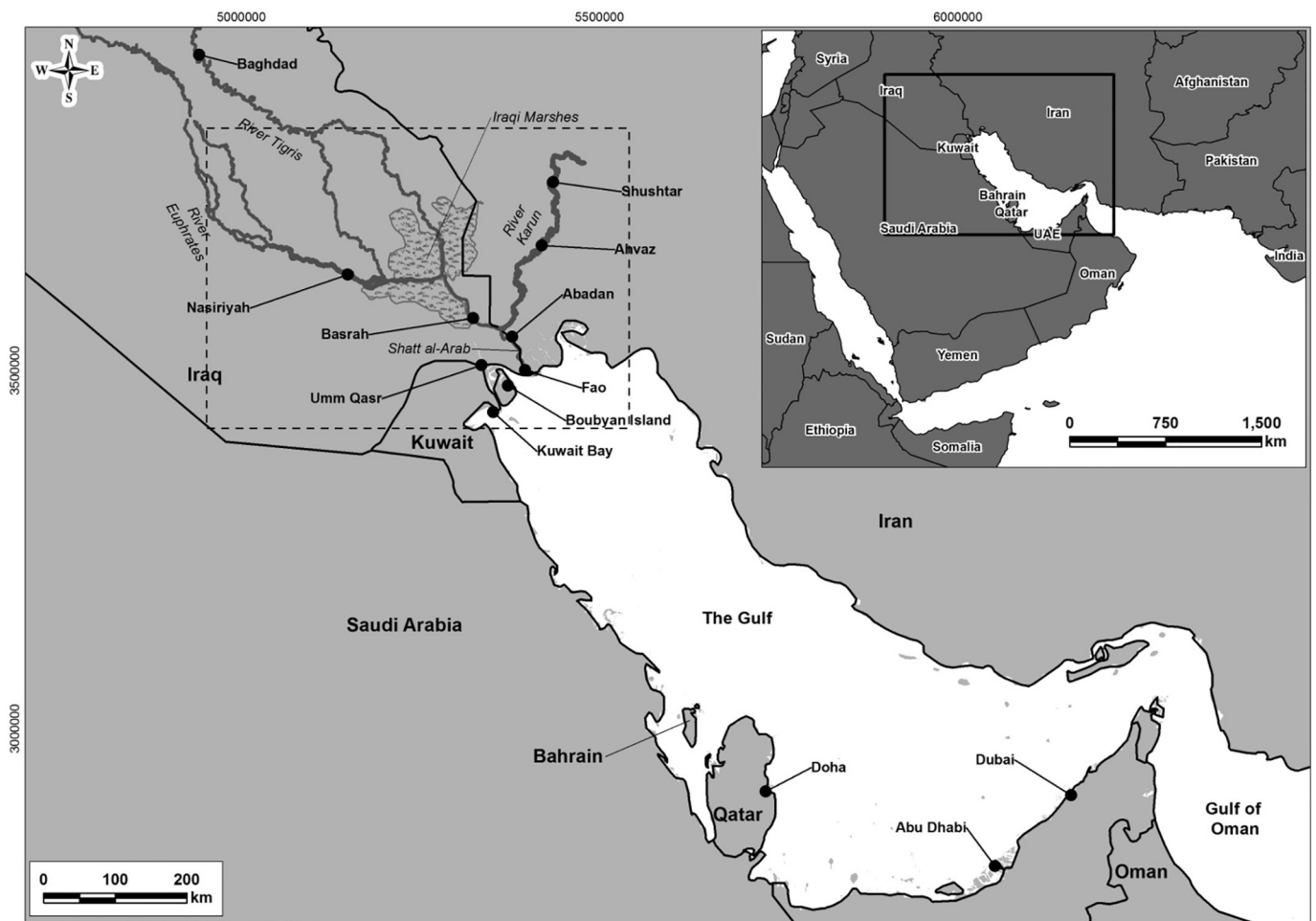


Fig. 1. Map of study area showing locations in text. Dashed line indicates area shown in Fig. 2.

indicated that the fauna had been adequately sampled (unpub. data).

In addition to these comparative surveys, data on specimens of *C. leucas* were collated from other sources, including photographs of elasmobranchs collected opportunistically from fish markets and landing sites in Kuwait, Qatar and Bahrain. Museum specimens were also examined, either directly in 2009 (Natural History Museum London, BMNH) or via good quality photographs in 2013 (South African Institute for Aquatic Biodiversity, SAIAB).

2.4. Estimation of biological parameters

Carcharhinus leucas with open umbilical scars were assumed to be within their first month of life (C. Simpfendorfer pers. comm. 2009). Estimates of ages for different size classes of *C. leucas* in the study area were made based on published studies from elsewhere, and size at birth locally using individuals recorded in Kuwait with open umbilical scars (75–83 cm STL, $n = 11$). Growth in the first and second years of life for *C. leucas* has been estimated as 16–18 and 13–16 cm yr⁻¹ respectively (Thorson and Lacy, 1982; Thorburn and Rowland, 2008) with similar estimates for first five years of life of 15–20 cm yr⁻¹ (Branstetter and Stiles, 1987; Tillett et al., 2011a). Based on the smallest and largest *C. leucas* with open umbilical scars recorded in Kuwait, and the slowest and fastest growth rates, these data support broad estimates of individuals in their first, second and third years of life locally being in the ranges of 75–103, 88–123, and 103–143 cm STL respectively. Although Heupel et al. (2007) based their criteria on sharks < 1 year old, the current study uses a slightly expanded definition of “young” sharks to be approximately 3 years or less (i.e. < 143 cm STL) given more limited

data available in this investigative study. Female *C. leucas* of approximately 200 cm STL or larger were assumed to be mature given a global range of 180–230 cm TL (Ebert et al., 2013) and a single 219 cm STL pregnant female landed in the UAE (Jabado et al., 2016). Furthermore, individuals of > 200 cm STL within the Tigris-Euphrates system were considered as being likely to be females, as available data from elsewhere supports a hypothesis that adult male *C. leucas* do not penetrate into lower salinity environments (Montoya and Thorson, 1982; Snelson et al., 1984; McCord and Lamberth, 2009; Curtis et al., 2011; Tillett et al., 2011b; Werry et al., 2011). ‘Juveniles’ in this study therefore span 143–200 cm STL. Length was broadly estimated from an anecdotal record of a shark given in imperial weight using *C. leucas* data from South Africa (Cliff and Dudley, 1991).

3. Results

3.1. Market surveys

The total number of shark individuals (all species) and total number of *C. leucas* individuals as a percentage of total sharks recorded in the comparable surveys is presented in Table 1. A total of 43 *C. leucas* were recorded, all but one of which were in Kuwait in 2008 and 2011. Only a single *C. leucas* was recorded in Qatar, and *C. leucas* was not recorded in Bahrain.

Four *C. leucas* individuals were recorded in Kuwait with open umbilical scars: two in 2008 (82 and 83 cm STL) and two in 2011 (both 76 cm STL). Length-frequency plots of individuals recorded in market surveys in Kuwait in 2008 and 2011 (Fig. 3) show young sharks

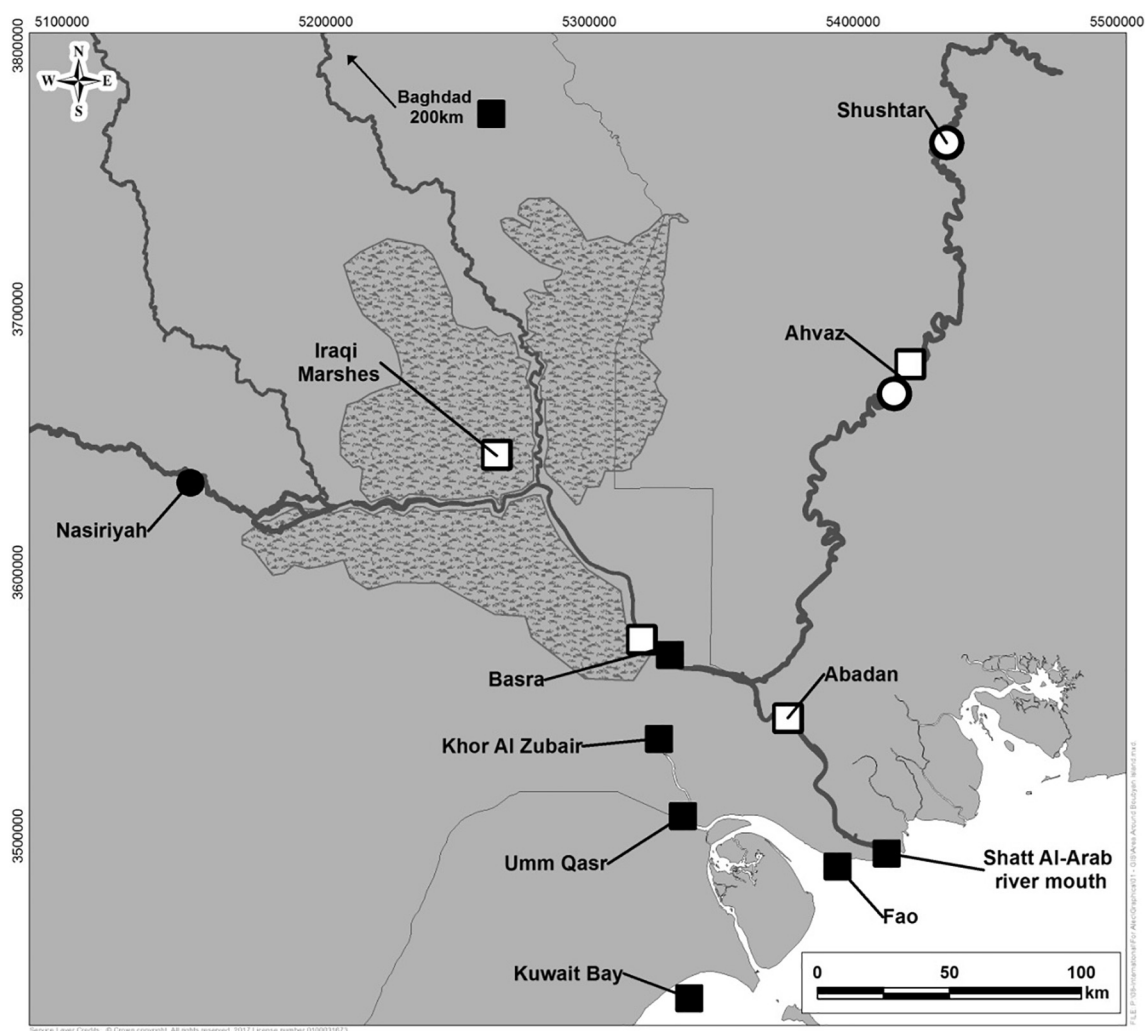


Fig. 2. Detail of study area showing locations of records of bull shark *Carcharhinus leucas* in Tables 2 and 3. ■ = specimen of young/juvenile; □ = anecdotal account of young/juvenile; ● = specimen of adult; ○ = anecdotal account of adult.

Table 1

Total number of sharks (all species), total number of bull shark *Carcharhinus leucas* as a proportion of this, and stretched total length (STL) of *C. leucas* recorded in quantitative fish market surveys of elasmobranchs in the month of April in Kuwait, Qatar and Bahrain.

	Kuwait 2008	Qatar 2009	Kuwait 2011	Bahrain 2012
Total no. sharks examined	1195	1707	422	961
Total no. <i>C. leucas</i>	26	1	16	0
<i>C. leucas</i> as a % of all sharks	2.17	0.06	3.79	0
Size range of <i>C. leucas</i> (cm STL)	82–183	180	76–139	–

dominating, with the 100–119 cm STL size classes most important. The single individual recorded in Qatar was 180 cm STL, and assumed to be of approximately 5 years of age.

In addition to the above comparable surveys, photographs from Kuwait from three separate dates in July and August 2009 confirmed the presence of several young *C. leucas* of 75–91 cm STL, including individuals of 75–81 cm STL with open umbilical scars (Table 2).

3.2. Other specimens

Specimens or records of young *C. leucas* collected outside of market

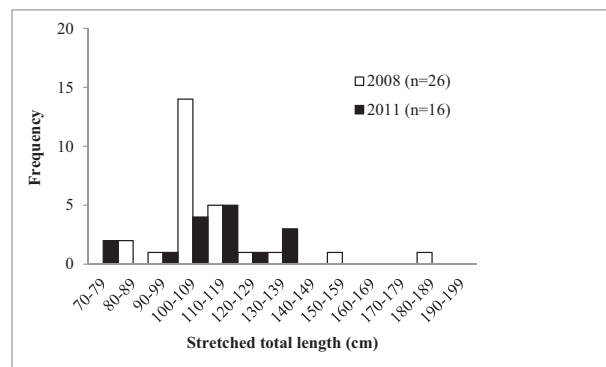


Fig. 3. Length-frequency distributions of bull shark *Carcharhinus leucas* recorded in fish market surveys of elasmobranchs in the month of April in Kuwait in 2008 and 2011.

surveys are presented in Table 2 and Figs. 2 and 4. These comprise individuals of 76.8–125 cm TL recorded over a wide time span and in a range of environments, including museum specimens registered in 1874 and 1924 collected in freshwater at Baghdad, over 500 km straight-line distance to the Gulf; several individuals recorded in estuarine conditions in or around the Shatt Al-Arab (in 1964, three separate instances in 2012 (one of which had an open umbilical scar) and probably in 2015), and in marine conditions in Kuwait Bay in 1966 and off Fao,

Table 2
Historical records (1874–2017) of young bull sharks *Carcharhinus leucas* in the northwestern Persian (Arabian) Gulf.

Year	Type of record	Date	n	Total length (TL)/stretched TL (STL) (cm)	Location	Notes	Source
1874*	Museum specimen	–	1	76.8 STL	River Tigris near Baghdad	*Date of registration	Günther (1874). BMNH 1874.4.28.9
1924*	Museum specimen	–	1	125 TL	River Tigris, Baghdad (Al-Karradah)	*Date of registration. Head only. '4 ft. 1 in.'	BMNH 1924.10.1.1. Assumed to be the "Carcharias lamia...taken in a fisherman's net just above Baghdad" reported by Kennedy (1937)
1964	Museum specimen	Sept	1	81 TL	Shatt Al-Arab river mouth.	–	SAIAB 6238. Dorsal fins measured by Roger Bills, collections manager SAIAB
1966	Field survey	July	1	78.3 TL	Kuwait Bay	Caught by angling 2 km off Seif Palace	Plate 3 in Kuronuma and Abe (1986)
2009	Fish market survey	July	4	76, 81, 81, 81 STL	Kuwait (Fahaheel fish market)	Open umbilical scars. 18th July	Recorded by Dareen Almojil
2009	Fish market survey	Aug	2	75, 80 STL	Kuwait (Sharq fish market)	Open umbilical scars. 31st Aug	Recorded by Dareen Almojil
2009	Fish market survey	Aug	2	77, 91 STL	Kuwait (Sharq fish market)	Open umbilical scar (77). 29th Aug	Recorded by Dareen Almojil
2012	Field survey	June	3	93, 101, 110 STL	Shatt Al-Arab River, Basrah ("station 3", Abu Al-Khasib)	As part of fish survey	Mohamed et al. (2013). Laith F. Lazem pers. comm
2012	Field survey	July	1	97 STL	Shatt Al-Arab River, Basrah ('station 3', Abu Al-Khasib)	As part of fish survey	Mohamed et al. (2013). Laith F. Lazem pers. comm
2012	Other	July	1	Not recorded, but with open umbilical scar	Umm Qasr (mouth of Shatt Al-Arab)	Dead individual on shoreline. Antero-ventral photo only, consistent with <i>C. leucas</i>	Photo from C. Childs, RSK Iraq, pers. comm. to ABMM 4th April 2013
2015	News article	–	1–3	≤100 STL	Shatt Al-Arab, Saybah province, Iraq	Photos show between 1 and 3 young <i>C. leucas</i> caught locally	Iraq News Agency (2015)
2017	Field survey	June	1	81 STL	Marine waters off Fao, Iraq	As part of fish survey	Abbas J. Al-Faisal & Audai Qasim pers. comm

Iraq, in 2017. In addition to those in Table 2, three *C. leucas* were recorded by Nasir (2000) in the Khor Al-Zubair in 1986–1987 and are considered as probably being young individuals based on capture methods used (seine and 2 m beam trawl) and catches dominated by small teleosts. In addition to these specimens of young *C. leucas*, a large (206 cm TL) and probably mature female was recorded in a drainage channel in southern Iraq (ca. 200 km straight-line distance from the Gulf) in 2007 (Hussain et al., 2012).

3.3. Anecdotal records

A number of anecdotal records of sharks in the fresh and estuarine waters of Iraq and Iran were made by European explorers, journalists, and medical and political officers (Table 3). These accounts indicated the size of shark individuals, allowing life history stage to be inferred (Table 3, Fig. 2). In addition, numerous reports of sharks biting humans in rivers and estuaries locally (Wilson, 1941; Hunt, 1951; Thesiger, 1964; Coad and Papahn, 1988; Coad and Al-Hassan, 1989) do not mention size of sharks, although the severe nature of some of the injuries (including to adult humans) may suggest some of these could be attributable to large, mature individuals. A further general observation was made by Kennedy (1937, p. 746) who noted "Sharks are not frequent visitors so high up the Tigris at Baghdad, but isolated ones are heard of every year. In the river at Basrah they are more common."

3.4. Assessment against Heupel et al. (2007) shark nursery criteria

Criteria 1 (young sharks more common than elsewhere) is broadly met by data from the comparable market surveys conducted in the month of April where young *C. leucas* were relatively abundant in the northwestern Gulf (Kuwait) (Table 1, Fig. 3), compared to their absence in the southern and central Gulf (Qatar and Bahrain) (Table 1). While these surveys were conducted in separate years, the consistent result for Kuwait in both 2008 and 2011, in addition to opportunistic records of young *C. leucas* in fish markets in Kuwait in 2009 (when none were recorded in a large sample size in Qatar), support the idea that young *C. leucas* are normally present around Kuwait, but not in the central and southern Gulf. The single *C. leucas* of 180 cm STL recorded from Qatar (estimated as approximately five years of age) is consistent with the species leaving river systems at around 4 years of age (Thorburn and Rowland, 2008) and subadults using shallow, warm, coastal marine habitats (Carlson et al., 2010; Werry et al., 2011). Further support for young *C. leucas* being present in the northwestern Gulf and the Tigris-Euphrates system is presented in Tables 2 and 3, whereas the author is unaware of literature or unpublished records of young *C. leucas* caught in the central and southern Gulf.

Criteria 2 (a tendency to remain or return in the area for extended periods), cannot be directly met using the data presented here. Residency can be tested by tagging techniques such as mark-recapture and acoustic tracking (Heupel et al., 2007), and has also been inferred from increases in mean size of cohorts over time (Froeschke et al., 2010); both of these techniques require significant resources and access to field study sites not possible in the present study. However, ample evidence exists from studies from elsewhere which support the idea of long-term presence of young *C. leucas* in river and estuarine systems. Heupel et al. (2010) found that most individuals monitored in the Caloosahatchee River, Florida, were present for periods of weeks to months, consistent with a nursery area. Yeiser et al. (2008) also found evidence for long-term use of estuarine areas by juvenile *C. leucas* in Florida, as did Froeschke et al. (2010) in Texas. Two studies from rivers in northern Australian rivers also provided supporting evidence consistent with young *C. leucas* remaining in freshwater environments: Thorburn and Rowland (2008) based on presence of a range of young size classes, and Tillett et al. (2011b), who used vertebral micro-chemistry. While data presented here does not provide direct evidence of residency, records of a range of size classes of young *C. leucas* (e.g. in



Fig. 4. Example specimens of young bull shark *Carcharhinus leucas* that support their repeated use of habitat in Iraq and Kuwait over multiple years. a) 76.8 cm STL museum specimen registered in 1874, River Tigris at Baghdad (BMNH 1874.4.28.9), ruler = 30 cm b) 81 cm TL museum specimen, Shatt Al-Arab River mouth, September 1964 (SAIAB 6238), ruler = 14 cm c) 76 cm STL fresh specimen with open umbilical scar, Sharq fish market, Kuwait, 6th April 2011, ruler = 30 cm d) 81 cm STL fresh specimen caught in fish survey, Iraqi marine waters near Fao, 5th June 2017.

Table 3

Anecdotal records of sharks (assumed here to be *Carcharhinus leucas*) that indicated size, along with inferred life history stage, from fresh and estuarine waters of Iraq and Iran.

Inferred life history stage	Record	Date	Location	Source
Young	"One morning I fished instead of shooting, and caught a fifteen-pound [ca. 70 cm pre-caudal length] shark"	1914–1917	River Karun at Ahvaz	Tab (1917) p. 129
Young	"I was told that shark fishing was the chief pastime there, and that young shark fried is excellent eating"	1914–1917	Basrah/Ahvaz	Tab (1917) p. 129
Young	"I asked if sharks were ever found in the Marshes, and Hasan said that a small one had been speared some years before"	1951–1958	Marshes of Iraq	Thesiger (1964) p. 156
Young/juvenile	"European observers state that [sharks biting humans] are about 4 to 6 ft. [122–183 cm] in length"	1940s	Abadan on the River Karun/Shatt Al-Arab	Anderson, in Hunt (1951)
Juvenile	"the C.O. caught his first shark...it was 4 ft. 10 in [147 cm]"	1940s	River Karun at Ahvaz	Hunt (1951), p.81
Adult (?female)	"Last month he slew a 9-foot [274 cm] shark that had killed two boys and a girl"	1907–1914	River Karun near Shushtar	Wilson (1941 p. 54)
Adult (?female)	"The C.O. ...was an enthusiastic fisherman who spent a great deal of time trying to catch a shark. The tales of those that got away were truly amazing. The one as big as a motor car is well remembered!"	1940s	River Karun at Ahvaz	Hunt (1951) p.80

Kuwait market samples, Fig. 2) does not refute, and could be consistent with, residency. Combined with well-documented examples of young *C. leucas* residency elsewhere, it is reasonable to propose that young *C. leucas* in the Tigris-Euphrates/northwestern Gulf system do show residency (and therefore could meet Criteria 2), until such time that this can be confirmed.

Criteria 3 (young sharks use the area or habitat repeatedly across years) is met with evidence from many different years. This evidence comprises 43 young *C. leucas* recorded in market surveys in 2008 and 2011 (Table 1) and at least a further 19 young *C. leucas* (Table 2) recorded in 1874, 1924, 1964, 1966, 2009, 2012, probably 2015, and 2017 (and probably in 1986–7), in addition to some anecdotal evidence of young sharks assumed to be *C. leucas* in the 1910s and 1950s (Table 3).

4. Discussion

4.1. Is the study area a nursery area?

The data collated and synthesized here significantly advance our understanding of the apex predator *C. leucas* in a previously neglected aquatic system of global importance, and provide compelling support that the Tigris-Euphrates/northwestern Gulf system is important habitat to young *C. leucas*. The evidence presented supports young *C. leucas* being relatively abundant compared to the central and southern

Gulf, and of young *C. leucas* repeatedly using the area, which broadly aligns with two of the three tenets of the Heupel et al. (2007) criteria (abundance and repeated use). Data cannot confirm, but could support, the third criteria of residency, although residency can reasonably be proposed based on ample evidence from studies of young *C. leucas* elsewhere. Other evidence provided also supports young, juvenile and adult *C. leucas* within the river system, consistent with known *C. leucas* reproductive ecology. While the low-resolution data presented does not answer the full suite of strict nursery criteria of Heupel et al. (2007), they nevertheless collectively provide evidence for a broad area of importance in the reproduction of *C. leucas* worthy of further consideration. As already noted, areas not qualifying as nurseries may still represent critical habitat to sharks. Froeschke et al. (2010) tested the criteria of Heupel et al. (2007) using a large, long-term dataset of young *C. leucas* in Texas, and concluded that areas not qualifying as nurseries may still be of significant importance.

4.2. Spatial scale

The low-resolution data presented here identifies a relatively broad geographic area of the lower Tigris-Euphrates system and adjacent coastal waters of the northwestern Gulf as being of importance to young and juvenile *C. leucas*. The relatively large size of this area does not necessarily preclude its potential importance: Heupel et al. (2007) do not comment on the spatial scale of nurseries, and other studies that

have identified elasmobranch nurseries span orders of magnitude in size. This has included a 27 km stretch of estuary in Florida, USA for *C. leucas* (Heupel and Simpfendorfer, 2011), a small bay of 225 km² in Queensland, Australia for a range of shark species (Simpfendorfer and Millward, 1993), defined coastal areas of 896 km² and 2505 km² in Florida for the smalltooth sawfish *Pristis pectinata* (Norton et al., 2012), and a major embayment of 35,678 km² in Mexico for the great white shark *Carcharodon carcharias* (Oñate-González et al., 2017). The relatively large area identified in the present study as habitat for young *C. leucas* may also be a result of major and multiple changes to the hydrological and salinity regime over the past century (FAO, 2017b), which may have dispersed *C. leucas* or prevented access to optimal habitat.

4.3. Applicability of approach in other situations

This study demonstrates the value of inexpensive alternative approaches to identifying critical habitat of an aquatic vertebrate where conventional surveys are not feasible. While applied to *C. leucas* here, it could usefully be applied to other taxa in data-poor regions. Species that are distinctive, impressive or noteworthy and found in close proximity to humans may be most likely to be recorded by fishers, explorers, museum collectors, newspapers, writers and citizens (e.g. Sáenz Arroyo et al., 2005) and these may be the best subjects for the alternative approach used in this study. *Carcharhinus leucas* lends itself well to this as key evidence presented here (such as early museum specimens and anecdotal accounts) was based on the noteworthiness of a shark occurring in river systems. The approach could therefore be applied to identifying *C. leucas* nurseries elsewhere, particularly in developing and least developed nations where research is lacking. As an example, intriguing preliminary evidence exists that the Betsiboka river in Madagascar may be worthy of further investigation as juvenile habitat both for *C. leucas* and the Critically Endangered largetooth sawfish *Pristis pristis* (Taniuchi et al., 2003). For Papua New Guinea where fieldwork is notoriously difficult, White et al. (2017) highlighted the merits of a similar approach by collating data from literature, museum specimens, and opportunistic surveys to identify areas of importance for Critically Endangered and Endangered sawfishes (Pristidae). There is also potential for the approach to fill data gaps for other distinctive threatened coastal and estuarine vertebrates in the developing world including other elasmobranchs (e.g. the Critically Endangered dagger-nose shark *Isogomphodon oxyrinchus* Lessa et al., 2006), teleosts, and marine mammals.

4.4. Importance and vulnerability of the Tigris-Euphrates population

The putative *C. leucas* nursery in the Tigris-Euphrates system may be exceptional both in terms of importance and vulnerability to anthropogenic threats.

The Tigris-Euphrates system is of major ecological importance as it may be the only permanent, significant estuary for approximately 10,000 km of arid northwestern Indian Ocean coastline. Estuaries appear to either be absent or only present as intermittent or minor features along the coasts of the entire Arabian Peninsula (Kuwait, Saudi Arabia, Qatar, Bahrain, UAE, Oman, Yemen, Jordan, Israel), and northeastern Africa (Egypt, Sudan, Eritrea, Djibouti, northern Somalia) (FAO, 2017b). As there is very strong support for *C. leucas* requiring river systems to breed successfully, this could elevate the Tigris-Euphrates system to exceptional importance for the taxon, especially if further work on the cryptic complex (Naylor et al., 2012) reveals more localised species with smaller ranges and populations. Evidence for female population structuring between *C. leucas* samples from Kuwait and South Africa found in molecular studies (Gulak, 2011) may also support the idea of a lack of suitable *C. leucas* nursery habitat in the northwestern Indian Ocean.

Young *C. leucas* show preferences for discrete salinity ranges, which

may reduce osmoregulatory costs and predation (Heupel and Simpfendorfer, 2008, 2011). Use of lower salinity habitats by young *C. leucas* is likely to be significantly impacted by reduction of access through damming (Hussain et al., 2012), reduction of freshwater discharge through both water management practices and predicted effects of climate change (Al-Yamani et al., 2007; Bozkurt and Sen, 2013), and discharge of vast quantities of brine from desalination plants (Hashim and Hajjaj, 2005). These are in addition to broader threats facing sharks in the northwestern Gulf such as intensive and largely unregulated fisheries and pollution (Moore et al., 2012, 2015). As there is evidence for reproductive philopatry in *C. leucas* (Tillett et al., 2012) where adults return to specific nurseries to give birth, chances of recovery from depletions may be greatly reduced (Hueter et al., 2005). Collectively, these present very significant challenges to a species that has otherwise lived alongside humans in the Tigris-Euphrates system since some of the earliest civilisations. The best opportunity to protect young *C. leucas* through measures such as fishery closures could come through incorporation into the management plans of some of the estuarine conservation areas that overlap with the study area, including Key Biodiversity Areas in Iraq (e.g. Khawr Abdullah, Khor Az-Zubayr), the Shatt al-Arab delta Ecologically or Biologically Significant Marine Area, and the Mubarak Al-Kabeer Reserve on Kuwait's Boubyan Island (Ramsar Sites Information Service, 2015; Birdlife International, 2017; Convention on Biological Diversity, 2017).

5. Conclusions

This study demonstrates that collating and critically examining disparate data from existing, remotely collected, and low-cost sources has the potential to provide useful information about critical habitat of threatened aquatic vertebrates, providing another toolkit option for conservationists. This study readily acknowledges its limitations: an expanded definition of 'young' sharks, small sample sizes in comparison to more traditional surveys, and falling just short of fulfilment of strict nursery identification criteria. Nevertheless, it provides convincing evidence of a highly threatened area of importance to young *C. leucas* in locations in which comprehensive boat-based field surveys of sharks are, realistically, unlikely to occur in the foreseeable future. Given the potential value and vulnerabilities of the putative nursery, the evidence presented here, albeit low-resolution, should provide adequate impetus for conservation efforts and the best on which to make decisions under the circumstances. *Carcharhinus leucas*, as a large iconic species spanning the freshwater-estuarine-marine environment and reliant on distant transboundary water management practices, could usefully serve as an indicator of catchment-wide and coastal ecosystem health.

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References

- Ajemian, M.J., Jose, P.D., Froeschke, J.T., Wildhaber, M.L., Stunz, G.W., 2016. Was everything bigger in Texas? Characterization and trends of a land-based recreational shark fishery. *Mar. Coast. Fish. Dyn. Manag. Ecosyst. Sci.* 8, 553–566.
- Al-Abdulrazzak, D., Pauly, D., 2017. Reconstructing historical baselines for the Persian/Arabian Gulf Dugong, *Dugong dugon* (Mammalia: Sirena). *Zool. Middle East* 63, 95–102.
- Almojil, D.K., Moore, A.B.M., White, W.T., 2015. Sharks and Rays of the Arabian/Persian Gulf. MBG Ltd.
- Al-Yamani, F., 2008. Importance of the freshwater influx from the Shatt-Al-Arab River on the Gulf marine environment. In: Abuzinada, A.H., Barth, H.J., Krupp, F., Böer, B., Al Abdessalaam, T.Z. (Eds.), *Protecting the Gulf's Marine Ecosystems from Pollution*. Birkhäuser Verlag, Switzerland.
- Al-Yamani, F.Y., Bishop, J.M., Al-Rafaie, K., Ismail, W., 2007. The effects of the river diversion, Mesopotamian marsh drainage and restoration, and river damming on the marine environment of the northwestern Arabian Gulf. *Aquat. Ecosyst. Health Manag.* 10, 277–289.
- Birdlife International, 2017. World Database of Key Biodiversity Areas. <http://www.keybiodiversityareas.org/site/mapsearch>, Accessed date: 29 October 2017.
- Bozkurt, D., Sen, O.L., 2013. Climate change impacts in the Euphrates-Tigris Basin based on different model and scenario simulations. *J. Hydrol.* 480, 149–161.
- Branstetter, S., Stiles, R., 1987. Age and growth-estimates of the bull shark, *Carcharhinus leucas*, from the northern Gulf of Mexico. *Environ. Biol. Fish* 20, 169–181.
- Braulik, G.T., Kasuga, M., Wittich, A., Kiszka, J.J., MacCaulay, J., Gillespie, D., Gordon, J., Said, S.S., Hammond, P.S., 2017. Cetacean rapid assessment: an approach to fill knowledge gaps and target conservation across large data deficient areas. *Aquat. Conserv. Mar. Freshwat. Ecosyst.* <http://dx.doi.org/10.1002/aqc.2833>.
- Cardena, D., Claus, K.B.J., Brunnenschweiler, J.M., 2016. Occurrence of juvenile bull sharks (*Carcharhinus leucas*) in the Navua River in Fiji. *Mar. Freshw. Res.* <http://dx.doi.org/10.1071/MF16005>.
- Carlson, J.K., Ribera, M.M., Conrath, C.L., Heupel, M.R., Burgess, G.H., 2010. Habitat use and movement patterns of bull sharks *Carcharhinus leucas* determined using pop-up satellite archival tags. *J. Fish Biol.* 77, 661–675.
- Cliff, G., Dudley, S.F.J., 1991. Sharks caught in the protective nets off Natal, South Africa. 4. The bull shark *Carcharhinus leucas* Valenciennes. *S. Afr. J. Mar. Sci.* 10, 253–270.
- Coad, B.W., Al-Hassan, L.A.J., 1989. Freshwater shark attacks at Basrah, Iraq. *Zool. Middle East* 3, 49–53.
- Coad, B.W., Papahn, F., 1988. Shark attacks in the rivers of southern Iran. *Environ. Biol. Fish* 23, 131–134.
- Convention on Biological Diversity, 2017. Shatt al-Arab Delta. Ecologically or Biologically Significant Marine Areas. Available at: <https://www.cbd.int/ebssa/>, Accessed date: 29 October 2017.
- Curtis, T.H., Adams, D.H., Burgess, G.H., 2011. Seasonal distribution and habitat associations of bull sharks in the Indian River Lagoon, Florida: a 30-year synthesis. *Trans. Am. Fish. Soc.* 140, 1213–1226.
- Dicken, M.L., Smale, M.J., Booth, A.J., 2006. Shark fishing effort and catch of the ragged-tooth shark *Carcharias taurus* in the South African competitive shore-angling fishery. *Afr. J. Mar. Sci.* 28, 589–601.
- Dulvy, N.K., Fowler, S.L., Musick, J.A., Cavanagh, R.D., et al., 2014. Extinction risk and conservation of the world's sharks and rays. *elife* 3, e00590.
- Ebert, D.A., Fowler, S., Compagno, L., 2013. *Sharks of the World: A Fully Illustrated Guide*. Wild Nature Press, Plymouth.
- FAO, 2017a. International Plan of Action for Conservation and Management of Sharks. Food and Agriculture Organization of the United Nations (FAO). Available at: <http://www.fao.org/ipoa-sharks/en/>, Accessed date: 6 January 2017.
- FAO, 2017b. AQUASTAT Food and Agriculture Organization of the United Nations (FAO). Available at: <http://www.fao.org/nr/water/aquastat>, Accessed date: 5 November 2017.
- Froeschke, J.T., Stunz, G.W., Sterba-Boatwright, B., Wildhaber, M.L., 2010. An empirical test of the 'shark nursery area concept' in Texas bays using a long-term fisheries-independent data set. *Aquat. Biol.* 11, 65–76.
- Garrick, J.A.F., 1982. Sharks of the genus *Carcharhinus*. In: NOAA (National Oceanic and Atmospheric Administration) Technical Report NMFS (National Marine Fisheries Service) Circular 445.
- Gulak, S.J.B., 2011. Phylogenetics and Phylogeography of the Bull Shark, *Carcharhinus leucas* (Valenciennes, 1839) (Master's thesis). University of Aberdeen.
- Günther, A., 1874. A contribution to the fauna of the River Tigris. *Ann. Mag. Nat. Hist.* 4, 36–38.
- Hashim, A., Hajjaj, M., 2005. Impact of desalination plants fluid effluents on the integrity of seawater, with the Arabian Gulf in perspective. *Desalination* 182, 373–393.
- Heupel, M.R., Simpfendorfer, C.A., 2008. Movement and distribution of young bull sharks *Carcharhinus leucas* in a variable estuarine environment. *Aquat. Biol.* 1, 277–289.
- Heupel, M.R., Simpfendorfer, C.A., 2011. Estuarine nursery areas provide a low-mortality environment for young bull sharks *Carcharhinus leucas*. *Mar. Ecol. Prog. Ser.* 433, 237–244.
- Heupel, M.R., Carlson, J.K., Simpfendorfer, C.A., 2007. Shark nursery areas: concepts, definition, characterization and assumptions. *Mar. Ecol. Prog. Ser.* 337, 287–297.
- Heupel, M.R., Yeiser, B.G., Collins, A.B., Ortega, L., Simpfendorfer, C.A., 2010. Long-term presence and movement patterns of juvenile bull sharks, *Carcharhinus leucas*, in an estuarine river system. *Mar. Freshw. Res.* 61, 1–10.
- Hueter, R.E., Heupel, M.R., Heist, E.J., Keeney, D.B., 2005. Evidence of philopatry in sharks and implications for the management of shark fisheries. *J. Northwest Atl. Fish. Sci.* 35, 239–247.
- Hunt, R.S., 1951. The sharks of Ahwaz. *J. R. Army Med. Corps* 1, 79–85.
- Hussain, N.A., Rasen, A.K., Al-Kafji, B.Y., Coad, B.W., 2012. Bull shark occurrence *Carcharhinus leucas* (Valenciennes, 1839) at the inland waters of southern Iraq. *J. Univ. Duhok* 15 (1), 140–143.
- Hussey, N.E., McCarthy, I.D., Dudley, S.F.J., Mann, B.Q., 2009. Nursery grounds, movement patterns and growth rates of dusky sharks, *Carcharhinus obscurus*: a long-term tag and release study in South African waters. *Mar. Freshw. Res.* 60, 571–583.
- IFC, 2012. International Finance Corporation. Guidance Note 6. Biodiversity Conservation and Sustainable Management of Living Natural Resources. Available at: https://www.ifc.org/wps/wcm/connect/a359a380498007e9a1b7f3336b93d75f/Updated_GN6-2012.pdf?MOD=AJPERES, Accessed date: 30 October 2017.
- Iraq News Agency, 2015. Sharks enter Shatt al-Arab (in Arabic). <http://www.iraqnewsagency.com>, Accessed date: 31 October 2017.
- Jabado, R.W., Al Ghais, S.M., Hamza, W., Shivji, M.M., Henderson, A.C., 2015. Shark diversity in the Arabian/Persian Gulf higher than previously thought: insights based on species composition of shark landings in the United Arab Emirates. *Mar. Biodivers.* 45, 719–731.
- Jabado, R.W., Al Ghais, S.M., Hamza, W., Robinson, D.P., Henderson, A.C., 2016. Biological data from sharks landed within the United Arab Emirates artisanal fishery. *Afr. J. Mar. Sci.* 38, 1–16.
- Jabado, R.W., Kyne, P.M., Pollom, R.A., Ebert, D.A., Simpfendorfer, C.A., Ralph, G.M., Dulvy, N.K. (Eds.), 2017. The Conservation Status of Sharks, Rays, and Chimaeras in the Arabian Sea and Adjacent Waters. Environment Agency – Abu Dhabi, UAE and IUCN Species Survival Commission Shark Specialist Group, Vancouver, Canada (236 pp).
- Kelagher, B.P., Tan, M., Figueira, W.F., Gillanders, B.M., Connell, S.D., Goldworthy, S.D., Hardy, N., Coleman, M.A., 2015. Fur seal activity moderates the effects of an Australian marine sanctuary on temperate reef fish. *Biol. Conserv.* 182, 205–214.
- Kennedy, W.P., 1937. Some additions to the fauna of Iraq. *J. Bombay Nat. Hist. Soc.* 39, 745–749.
- Knip, D.M., Heupel, M.R., Simpfendorfer, C.A., Tobin, A.J., Moloney, J., 2011. Wet-season effects on the distribution of juvenile pigeye sharks *Carcharhinus amblopinens*, in tropical nearshore waters. *Mar. Freshw. Res.* 62, 658–667.
- Kuronuma, K., Abe, Y., 1986. Fishes of the Arabian Gulf. Kuwait Institute for Scientific Research, Safat, Kuwait.
- Lessa, R., Charvet-Almeida, P., Santana, F.M., Almeida, Z., 2006. *Isogomphodon oxyrinchus*. The IUCN red list of threatened species 2006: eT60218A12323498. <https://doi.org/10.2305/IUCN.UK.2006.RLTS.T60218A12323498.en> (Downloaded on 26 October 2017).
- Lotze, H.K., McClenachan, L., 2014. Marine historical ecology: informing the future by learning from the past. In: Bertness, M.D., Silliman, B.R., Bruno, J.F., Stachowicz, J.J. (Eds.), *Marine Community Ecology and Conservation*. Sinauer, pp. 165–200.
- McCord, M.E., Lamberth, S.J., 2009. Catching and tracking the world's largest Zambezi (bull) shark *Carcharhinus leucas* in the Breede Estuary, South Africa: the first 43 hours. *Afr. J. Mar. Sci.* 31, 107–111.
- Mohamed, A.R.M., Hussein, S.A., Lazem, L.F., 2013. Spatiotemporal variability of fish assemblage in the Shatt Al-Arab River, Iraq. *J. Agric. Sci.* 26, 43–59.
- Montoya, R.V., Thorson, T.B., 1982. The bull shark (*Carcharhinus leucas*) and largemouth sawfish (*Pristis perotteti*) in Lake Bayano, a tropical man-made impoundment in Panama. *Environ. Biol. Fish* 7, 341–347.
- Moore, A.B.M., 2010. The smallest stingray *Dasyatis microps* (Myliobatiformes: Dasyatidae) in the Gulf: previously unreported presence of a large, rare elasmobranch. *Zool. Middle East* 49, 101–103.
- Moore, A.B.M., 2011. Elasmobranchs of the Persian (Arabian) Gulf: ecology, human aspects and research priorities for their improved management. *Rev. Fish Biol. Fish.* 22, 35–61.
- Moore, A.B.M., 2015. A review of sawfishes (Pristidae) in the Arabian region: diversity, distribution, and functional extinction of large and historically abundant marine vertebrates. *Aquat. Conserv. Mar. Freshwat. Ecosyst.* 25, 656–677.
- Moore, A.B.M., McDavitt, M., 2009. Arabian sharks and rays: traditional uses and cultural importance. *Shark Focus* 34, 6–7.
- Moore, A.B.M., Peirce, R., 2013. Composition of elasmobranch landings in Bahrain. *Afr. J. Mar. Sci.* 35, 593–596.
- Moore, A.B.M., McCarthy, I.D., Carvalho, G.R., Peirce, R., 2012. Species, size, sex and male maturity composition of previously unreported elasmobranch landings in Kuwait, Qatar and Abu Dhabi Emirate. *J. Fish Biol.* 80, 1619–1642.
- Moore, A.B.M., Bolam, T., Lyons, B.P., Ellis, J.R., 2015. Concentrations of trace elements in a rare and threatened coastal shark from the Arabian Gulf (smoothtooth blacktip *Carcharhinus leiodon*). *Mar. Pollut. Bull.* 100, 646–650.
- Nasir, N.A., 2000. The food and feeding relationships of the fish communities in the in-shore waters of Khor Al-Zubair, north-west Arabian Gulf. *Cybius* 24, 89–99.
- Naylor, G.J.P., Cairns, J.N., Jensen, K., Rosana, K.A.M., White, W.T., Last, P.R., 2012. A DNA sequence-based approach to the identification of shark and ray species and its implications for global elasmobranch diversity and parasitology. *Bull. Am. Mus. Nat. Hist.* 367, 1–262.
- Norton, S.L., Wiley, T.R., Carlson, J.K., Frick, A.L., Poulakis, G.R., Simpfendorfer, C.A., 2012. Designating critical habitat for juvenile endangered smalltooth sawfish in the United States. *Mar. Coast. Fish. Dyn. Manag. Ecosyst. Sci.* 4, 473–480.
- Onate-González, E.C., Sosa-Nishizaki, O., Herzka, S.Z., Lowe, C.G., Lyons, K., Santana-Morales, O., Sepúlveda, C., Guerrero-Ávila, C., García-Rodríguez, E., O'Sullivan, J.B., 2017. Importance of Bahía Sebastian Vizcaino as a nursery area for white sharks (*Carcharodon carcharias*) in the Northeastern Pacific: a fishery dependent analysis. *Fish. Res.* 188, 125–137.
- Ramsar Sites Information Service, 2015. Mubarak Al-Kabeer Reserve. (Accessed 29th October 2017).
- Sáenz Arroyo, A., Roberts, C.M., Torre, J., Carino-Olvera, M., 2005. Using fishers' anecdotes, naturalists' observations and grey literature to reassess marine species at risk:

- the case of the Gulf grouper in the Gulf of California, Mexico. *Fish Fish.* 6, 121–133.
- Simpfendorfer, C.A., Millward, N.E., 1993. Utilisation of a tropical bay as a nursery area by sharks of the families Carcharhinidae and Sphyrnidae. *Environ. Biol. Fish.* 37, 337–345.
- Simpfendorfer, C.A., Elhassan, I., Jabado, R.W., Valinassab, T., Moore, A.B.M., 2017. Bull shark *Carcharhinus leucas*. Regional red list assessment. In: Jabado, R.W., Kyne, P.M., Pollom, R.A., Ebert, D.A., Simpfendorfer, C.A., Ralph, G.M., Dulvy, N.K. (Eds.), *The Conservation Status of Sharks, Rays, and Chimaeras in the Arabian Sea and Adjacent Waters*. Environment Agency – Abu Dhabi, UAE and IUCN Species Survival Commission Shark Specialist Group, Vancouver, Canada (236 pp).
- Snelson, F.F., Mulligan, T.J., Williams, S.E., 1984. Food habits, occurrence and population structure of the bull shark, *Carcharhinus leucas* in Florida coastal lagoons. *Bull. Mar. Sci.* 34, 71–80.
- Tab, B., 1917. *On the Road to Kut: A Soldier's Story of the Mesopotamian Campaign*. Hutchinson & Co., London.
- Taniuchi, T., Ishihara, H., Tanaka, S., Hyodo, S., Murakami, M., Séret, B., 2003. Occurrence of two species of elasmobranchs *Carcharhinus leucas* and *Pristis microdon*, in Betsiboka River, west Madagascar. *Cybio* 27, 237–241.
- Thesiger, W., 1964. *The Marsh Arabs*. Penguin, London.
- Thorburn, D.C., Rowland, A.J., 2008. Juvenile bull sharks *Carcharhinus leucas* (Valenciennes, 1839) in northern Australian rivers. In: *The Beagle, Records of the Museums and Art Galleries of the Northern Territory*, 24, pp. 79–86.
- Thorson, T.B., 1972. The status of the bull shark, *Carcharhinus leucas*, in the Amazon River. *Copeia* 1972 (3), 601–605.
- Thorson, T.B., Lacy, E.J., 1982. Age, growth rate and longevity of *Carcharhinus leucas* estimated from tagging and vertebral rings. *Copeia* 1982 (1), 110–116.
- Tillett, B.J., Meekan, M.G., Field, I.C., Hua, Q., Bradshaw, C.J.A., 2011a. Similar life-history traits in bull (*Carcharhinus leucas*) and pig-eye (*C. amboinensis*) sharks. *Mar. Freshw. Res.* 62, 850–860.
- Tillett, B.J., Meekan, M.G., Parry, D., Munksgaard, N., Field, I.C., Thorburn, D., Bradshaw, C.J.A., 2011b. Decoding fingerprints: elemental composition of vertebrae correlates to age-related habitat in two morphologically similar sharks. *Mar. Ecol. Prog. Ser.* 434, 133–142.
- Tillett, B.J., Meekan, M.G., Field, I.C., Thorburn, D.C., Ovenden, J.R., 2012. Evidence for reproductive philopatry in the bull shark *Carcharhinus leucas*. *J. Fish Biol.* 80, 2140–2158.
- US Fish & Wildlife Service, 2017. *Endangered species: listing and critical habitat*. Available at: <https://www.fws.gov/endangered/what-we-do/critical-habitats-faq.html>, Accessed date: 20 October 2017.
- Valinassab, T., Daryanabard, R., Dehghani, R., Pierce, G.J., 2006. Abundance of demersal fish resources in the Persian Gulf and Oman Sea. *J. Mar. Biol. Assoc. U. K.* 86, 1455–1462.
- Werry, J.M., Lee, S.Y., Otway, N.M., Hu, Y., Sumpton, W., 2011. A multi-faceted approach for quantifying the estuarine-nearshore transition in the life cycle of the bull shark, *Carcharhinus leucas*. *Mar. Freshw. Res.* 62, 1421–1431.
- White, W.T., 2007. Catch composition and reproductive biology of whaler sharks (Carcharhiniformes: Carcharhinidae) caught by fisheries in Indonesia. *J. Fish Biol.* 71, 1512–1540.
- White, W.T., Appleyard, S.A., Kyne, P.M., Mana, R.R., 2017. Sawfishes in Papua New Guinea: a preliminary investigation into their status and level of exploitation. *Endanger. Species Res.* 32, 277–291.
- Wilson, A., 1941. *SW Persia: A Political Officer's Diary 1907–1914*. Oxford University Press, London.
- Yeiser, B.G., Heupel, M.R., Simpfendorfer, C.A., 2008. Occurrence, home range and movement patterns of juvenile bull (*Carcharhinus leucas*) and lemon (*Negaprion brevirostris*) sharks within a Florida estuary. *Mar. Freshw. Res.* 59, 489–501.
- Zorzi, G.D., 1995. The biology of freshwater elasmobranchs: an historical perspective. *J. Aquaric. Aquat. Sci.* 7, 10–31.